

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
13 September 2001 (13.09.2001)

PCT

(10) International Publication Number
WO 01/66955 A2

(51) International Patent Classification⁷: **F15B**
(21) International Application Number: PCT/US01/05639
(22) International Filing Date: 22 February 2001 (22.02.2001)
(25) Filing Language: English
(26) Publication Language: English
(30) Priority Data:
09/521,537 8 March 2000 (08.03.2000) US

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

(71) Applicant: ROSEMOUNT INC. [US/US]; 12001 Technology Drive, Eden Prairie, MN 55344 (US).

Published:

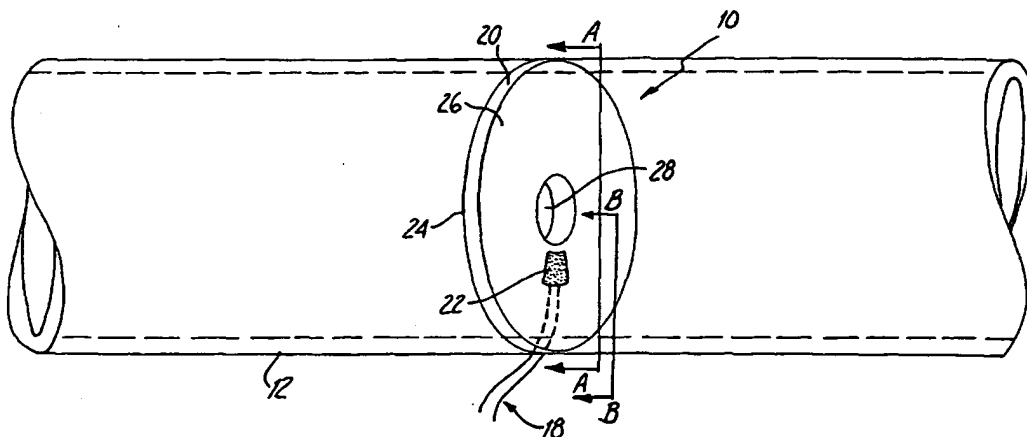
— without international search report and to be republished upon receipt of that report

(72) Inventors: WIKLUND, David, E.; 17918 South Shore Lane West, Eden Prairie, MN 55346 (US). KROUTH, Terrence, F.; 8722 Stanley Trail, Eden Prairie, MN 55347 (US). BRODEN, David, A.; 3045 166th Lane N.W., Andover, MN 55301 (US). SCHUMACHER, Mark, S.; 322 East Minnehaha Parkway, Minneapolis, MN 55419 (US).

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(74) Agents: KAUL, Brian, D. et al.; Westman, Champlin & Kelly, P.A., International Centre, Suite 1600, 900 Second Avenue South, Minneapolis, MN 55402-3319 (US).

(54) Title: BI-DIRECTIONAL DIFFERENTIAL PRESSURE FLOW SENSOR



(57) Abstract: Disclosed is a bi-directional differential pressure flow sensor (10) that is configured to establish a direction and flow rate of a fluid flow. The flow sensor (10) includes a flow restriction member (20), a differential pressure sensor (22), and processing electronics (50). The flow restriction member (20) is configured to produce a pressure drop when placed inline with the fluid flow. The differential pressure sensor (22) is embedded or integral with the flow restriction member and produces a differential pressure signal that is indicative of the pressure drop. The processing electronics (50) produces a flow rate signal that is indicative of the direction and flow rate of the fluid flow as a function of the differential pressure signal.

WO 01/66955 A2

-1-

BI-DIRECTIONAL DIFFERENTIAL PRESSURE FLOW SENSOR

BACKGROUND OF THE INVENTION

The present invention relates to a bi-
5 directional flow sensor used to measure flow rate of
a fluid flow. More particularly, the present
invention relates to a differential pressure flow
sensor of the type using a flow restriction member to
produce a pressure drop within the fluid flow, a
10 measurement of which can be used to establish the
direction and flow rate of a fluid flow.

Fluid flow sensors can be used in many
different applications, such as in industrial process
control environments, to measure flow rates of
15 process fluids (liquids and gases) and provide flow
signals for flow indicators, controls, and flow
volume metering. Differential pressure flow sensors
measure the fluid flow rate in a pipe or conduit by
measuring a pressure drop across a discontinuity
20 within the pipe. One way to form the discontinuity
is to place a flow restriction member or primary
element within the pipe to produce the desired
pressure drop. One such flow restriction member is
an orifice plate that restricts the fluid flow and
25 produces the measured pressure drop. An example of
an orifice plate is the orifice restriction used in
Model 1195 Integral Orifice produced by Rosemount,
Inc. of Eden Prairie, Minnesota. These flow

-2-

restriction members are generally uni-directional allowing for flow rate measurements of fluid flows moving in a single direction.

Typical flow rate measuring systems tap the pipe containing the fluid flow on either side of the flow restriction member and measure the pressure at each tap and use an external pressure sensor to obtain the pressure drop. Impulse or gauge lines filled with fluid communicate the pressure at each tap to the external pressure sensor. Such systems have relatively high installation costs due to the need to attach an external pressure sensor to the pipe, and to provide leakage protection at the locations where the pipe is tapped. Additionally, impulse lines attenuate the pressure signals and introduce delays thereby reducing the sensitivity and responsiveness of the flow measurement. Also, in gas applications, condensing gases in the impulse lines can cause erroneous readings. Furthermore, the use of impulse lines can also render these types of flow measuring systems sensitive to their position. As a result, they must be recalibrated each time their position changes.

SUMMARY OF THE INVENTION

A bi-directional differential pressure flow sensor is provided that is configured to establish a direction and flow rate of a fluid flow. The flow sensor includes a flow restriction member, a differential pressure sensor, and processing

-3-

electronics. The flow restriction member is configured to produce a pressure drop when placed inline with the fluid flow. The differential pressure sensor is embedded or integral with the flow restriction member and produces a differential pressure signal that is indicative of the pressure drop. The processing electronics produces a flow rate signal that is indicative of the direction and flow rate of the fluid flow as a function of the differential pressure signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified diagram showing a flow sensor attached to a pipe in a process plant.

FIG. 2 shows a flow sensor, in accordance with one embodiment of the invention, positioned within a pipe.

FIGS. 3a-3c are cross-sectional views of embodiments of a flow restriction member taken along line A-A of FIG. 2 with some elements removed.

FIGS. 4-6 are cross-sectional views of embodiments of the invention taken along line B-B of FIG. 2.

FIGS. 7 and 8 are simplified block diagrams of circuitry used to perform flow rate calculations in accordance with various embodiments of the invention.

FIG. 9 is a cross-sectional view of a flow sensor installed in a pipe.

-4-

FIG. 10 is a cross-section view of another embodiment of the invention.

FIGS. 11 and 12 are cross-sectional views of other embodiments of the invention.

5 FIGS. 13a-f show flow restriction members in accordance with various embodiments of the invention.

FIG. 14 is a cross-sectional view of another embodiment of the invention.

10 DETAILED DESCRIPTION

The present invention provides a bi-directional differential pressure flow sensor, in which components of a differential pressure sensor are integral with the flow restriction member. The
15 flow sensor can be placed inline with the fluid flow such that the flow restriction member produces a pressure drop which can be sensed by the differential pressure sensor. The differential pressure sensor is configured to produce a pressure signal that is
20 indicative of the sensed pressure drop. Processing electronics, coupled to the differential pressure sensor, is adapted to produce a flow rate signal that is indicative of the magnitude and direction of a flow rate of the fluid flow as a function of the
25 differential pressure signal.

FIG. 1 depicts an example of a processing plant and illustrates an environment in which the flow sensor of the present invention, generally designated as 10, can be used. Flow sensor 10 is

-5-

installed inline with pipe 12 to produce and sense a pressure drop which can be used to determine the flow rate of a fluid flow through pipe 12 and into and out of process tank 14. The fluid flow can be of liquid or gas. Flow sensor 10 can be electronically coupled to control system 16 or other processing electronics, over two-wire control loop 18. Control system 16 is typically remotely located in control room 17 of the processing plant. Control system 16 can be configured to control, and receive flow-related information from, flow sensor 10 over two-wire control loop 18 using a standard 4-20 mA analog signal, or a digital signal in accordance with a digital communication protocol such as Highway Addressable Remote Transducer (HART®), FOUNDATION™ Fieldbus, Profibus PA, Profibus DP, Device Net, Controller Area Network (CAN), Asi, and other digital communication protocols commonly used in the industry. Additionally, flow sensor 10 can be a low power flow sensor, which is completely powered by energy received over control loop 18.

The flow rate signal produced by flow sensor 10 is indicative of the flow rate of the fluid flow as well as its direction. For example, if the flow rate signal is an analog signal (4-20 mA), the flow rate and the direction of the fluid flow can be indicated by the magnitude of the signal. A flow rate of zero can be indicated by zero flow rate magnitude, such as a current magnitude of 12 mA. A

-6-

fluid flow moving in a negative direction, or a negative fluid flow, can be indicated by a flow rate signal having a current magnitude of less than the zero flow rate magnitude. A positive fluid flow can be indicated by a flow rate signal having a current magnitude that is greater than the zero flow rate magnitude. The difference between of the magnitude of the flow rate signal and the zero flow rate magnitude can be used to establish the flow rate of the positive or negative fluid flows. For example, an increase in the difference between magnitude of the flow rate signal and the zero flow rate magnitude could indicate an increase in the flow rate of the positive or negative fluid flow. Also, the digital protocols mentioned above can also communicate the direction and flow rate of the fluid flow.

FIG. 2 shows a simplified illustration of one embodiment of flow sensor 10 within pipe 12. Flow sensor 10 generally includes flow restriction member or primary element 20 and differential pressure sensor 22 embedded in or integral with flow restriction member 20. In general, flow restriction member 20 is a bi-directional flow restriction member that forms a discontinuity within the fluid flow which produces a pressure drop across first and second sides 24, 26 of flow restriction member 20. A positive pressure drop occurs when the pressure at first side 24 is greater than the pressure at second side 26. The positive pressure drop relates to a

-7-

positive fluid flow or a fluid flow moving from left to right or from first side 24 to second side 26. A negative pressure drop occurs when the pressure at first side 24 is less than the pressure at second side 26. The negative pressure drop relates to a negative fluid flow or a fluid flow moving from right to left or from second side 26 to first side 24. The greater the magnitude of the pressure drop the faster the flow rate of the fluid flow. As a result, the pressure drop is indicative of both the direction of the fluid flow and its flow rate. Those skilled in the art will appreciate that many different forms of flow restriction member 20 could be used to produce the desired pressure drop. These include, for example, orifice plates having concentric and eccentric orifices, plates without orifices, wedge elements consisting of two non-parallel faces which form an apex, or other commonly used flow restriction members.

The embodiment of flow restriction member 20 shown in FIG. 2, includes fluid flow passageway or orifice 28 extending between first and second sides 24, 26. Flow restriction member 20 is placed inline with a fluid flow through pipe 12 forcing the fluid flow to travel through fluid flow passageway 28 resulting in a pressure drop across first and second sides 24, 26 of flow restriction member 20. Differential pressure sensor 22 is configured to sense the pressure at both first and second sides 24,

-8-

26 of flow restriction member 20 and produce a differential pressure signal that is indicative of the pressure drop or pressure difference between first and second sides 24, 26. As a result, the
5 differential pressure signal can be used to calculate the direction of the fluid flow and its flow rate.

FIGS. 3a-3c show cross-sectional views of various embodiments of flow restriction member 20 taken at line A-A of FIG. 2. Differential pressure
10 sensor 22 is not shown to simplify the illustrations. Fluid flow passageway 28 is symmetric about axis 29 and is defined by first and second throat portions 30, 32 corresponding to first and second sides 24, 26, respectively. These embodiments of flow
15 restriction member 20 allow flow sensor 10 to operate in bi-directional fluid flows. In FIG. 3a, throat portions 30, 32 of flow restriction member 20 are perpendicular to first and second sides 24, 26. Alternatively, first and second throat portions 30,
20 32 can be tapered toward the center of fluid flow passageway 28, as shown in FIGS. 3b and 3c.

Flow sensor 10 integrates differential pressure sensor 22 with the flow restriction member 20 to form a single unit which can be positioned
25 inline with a fluid flow. FIGS. 4-6 show cross-sectional views of various embodiments of flow sensor 10 taken along line B-B of FIG. 2. In each of the depicted embodiments, differential pressure sensor 22 measures the pressure drop across flow restriction

-9-

member 20 by coupling differential pressure sensor 22 to the pressures at first and second sides 24 and 26. Differential pressure sensor 22 could be, for example, a piezoresistive differential pressure sensor, which operates on strain gauge technology, a capacitance-based differential pressure cell, in which the capacitance of differential pressure sensor 22 changes as a function of the pressure drop, or any other suitable differential pressure sensor commonly used in the industry. Differential pressure sensor 22 produces a pressure signal that is indicative of the pressure drop which can be provided to processing electronics to calculate the flow rate of the fluid flow.

15 In one embodiment of flow sensor 10, differential pressure sensor 22 is coupled to the pressures at first and second sides 24, 26 through first and second openings 34, 36, respectively, as shown in FIG. 4. Since this embodiment does not use impulse lines or fill fluid to couple to the pressures at first and second sides 24, 26, it is insensitive to position. As a result, this embodiment of differential pressure sensor 22 can be moved without having to recalibrate flow sensor 10.

25 Differential pressure sensor 22 can be isolated from the fluid in pipe 12 by an isolator diaphragm or a coating 37 on the sides of differential pressure sensor 22 that are exposed to first and second openings 34, 36. Coating 37 is preferably impervious

-10-

to the fluid to protect sensor 22. However, coating 37 should transfer the process pressure to sensor 22 and does not prevent differential pressure sensor 22 from sensing the pressure at first and second sides 24, 26. Any material that electrically insulates the sensor from the process fluid yet still transfers the fluid pressure to the sensor can be used. Examples of materials that could be used as coating 37 are grease or potting compounds.

10 In another embodiment of flow sensor 10, differential pressure sensor 22 is isolated from fluid flow by way of first and second diaphragms 38, 40 and corresponding first and second cavities 42, 44, as shown in FIG. 5. Cavities 42, 44 are
15 preferably filled with a suitable fill fluid for transmitting the pressure sensed by first and second diaphragms 38, 40 at the respective first and second sides 24, 26 to differential pressure sensor 22. The fill fluid may include silicone, oil, glycerin and
20 water, propylene glycol and water, or any other suitable fluid which preferably is substantially incompressible. This embodiment of the invention is somewhat sensitive to position, unlike the embodiment depicted in FIG. 4, due to the fill fluid. However,
25 this sensitivity to position can be reduced by reducing the thickness of flow restriction member 20 or by positioning first and second diaphragms 38, 40 closer to differential pressure sensor 22.

-11-

FIG. 7 shows a simplified block diagram of one embodiment of processing circuitry 50 used by the present invention to produce a flow rate signal that is indicative of the direction and flow rate of the fluid flow. Here, differential pressure sensor 22 provides processing electronics 50 with the pressure signal that is indicative of the pressure drop across flow restriction member 20. Processing electronics 50 generally includes analog-to-digital (A/D) converter 52, microprocessor 54, and input/output (I/O) port 56. A/D converter 52 digitizes the pressure signal received from differential pressure sensor 22 and provides the digitized pressure signal to microprocessor 54. Microprocessor 54 is configured to establish the direction of the fluid flow by the sign of the pressure signal; either positive or negative. Microprocessor 54 is further configured to calculate the flow rate of the fluid flow as a function of the absolute value of the digitized pressure signal. For example, microprocessor 54 could use the following equations to calculate mass flow rate (Q_m) and volume flow rate

$$Q_m = NC_d Y \frac{d^2}{\sqrt{1-\beta^4}} \sqrt{\rho h} \quad Q_v = NC_d Y \frac{d^2}{\sqrt{1-\beta^4}} \frac{\sqrt{h}}{\sqrt{\rho}}$$

(Q_v):

Where:

25 Q_m = mass flow rate
 Q_v = volumetric flow rate

-12-

- N = Units conversion factor (constant)
- C_a = primary element discharge coefficient
(relates to the geometry of the throat)
- 5 Y = gas expansion factor (Y=1.0 for liquids)
- d = primary element throat diameter
- β = primary element beta ratio (ratio of throat area to pipe area)
- 10 ρ = fluid density
- h = absolute value of the differential pressure measured by differential pressure sensor 22.

15 Microprocessor 54 is further configured to produce a flow rate signal through I/O port 56 that is indicative of the direction and flow rate of the fluid flow. The flow rate signal can be delivered to a control system 16 (FIG. 1), as previously

20 discussed. In one aspect of the invention, the differential pressure signal produced by differential pressure sensor 22 is provided as an output, which can be used to correct for errors, such as those due to spikes in the measurements. Such spikes can be

25 problematic when using the invention to measure piston position in hydraulic systems as a function of flow of hydraulic fluid.

-13-

Referring back to FIG. 6, another embodiment of flow sensor 10 includes temperature sensor 58, which can be used to measure the temperature of the fluid flow and/or the operating temperature of differential pressure sensor 22. Temperature sensor 58 could be, for example, a resistive temperature detector (RTD) or other suitable temperature sensing device. Temperature sensor 58 is configured to produce a temperature signal that is indicative of the sensed temperature, which can be provided to processing electronics 50 at A/D converter 52, as shown in FIG. 8. A/D converter 52 digitizes the temperature signal and provides the digitized temperature signal to microprocessor 54. Microprocessor 54 can be configured to use the digitized temperature signal to perform various fluid parameter calculations, such as viscosity and density calculations, the results of which can be used by microprocessor 54 to calculate the flow rate of the fluid flow. Additionally, microprocessor 54 can use the temperature signal to provide temperature compensation to the pressure signal received from differential pressure transmitter 22. Microprocessor 54 can produce a flow rate signal that is indicative of the flow rate of the fluid flow as a function of the differential pressure signal and the temperature signal, that can be fed to other processing circuitry, such as to control system 16, through I/O port 56.

-14-

Yet another embodiment of flow sensor 10 includes static pressure sensor 59, shown in FIG. 6. Static pressure sensor 59 is configured to sense the line pressure of the fluid flow and produce a line pressure signal that is indicative of the sensed pressure. Due to the position of static pressure sensor 59, the line pressure signal could require correction for stagnation pressure effects. The line pressure signal can be used, for example, to calculate the density of a gas for use in gas flow rate calculations. Static pressure sensor 59 can be a piezoresistive pressure sensor or a capacitance-based pressure sensor. Coating 37 can be used to protect static pressure sensor 59 from the fluid flow if necessary. Alternatively, static pressure sensor 59 can be isolated from the fluid flow using an diaphragm with an oil fill fluid.

The line pressure signal produced by static pressure sensor 59 can be provided to processing electronics 50 as a parameter that can be used to calculate the flow rate of the fluid flow, as indicated in FIG. 8. The line pressure signal is received by processing electronics 50 at A/D converter 52, which provides the line pressure signal to microprocessor 54 in a digital form. Microprocessor 54 can produce a flow rate signal that is indicative of the flow rate of the fluid flow as a function of the differential pressure signal from differential pressure sensor 22 and the line pressure

-15-

signal. The flow rate, line pressure, differential pressure or temperature signals can be fed to other processing circuitry, such as to control system 16, through I/O port 56. Another embodiment of flow sensor 10 includes processing electronics 50, as shown in FIG. 6. Here, processing electronics 50 is embedded in or integral with flow restriction member 20. Processing electronics 50 is placed in electronic communication with differential pressure sensor 22 to receive the differential pressure signal, as shown in FIG. 7. Processing electronics 50 can be further configured to receive signals from temperature sensor 58 and/or static pressure sensor 59, as indicated in FIG. 8. Processing electronics 50 can perform the various calculations discussed above relating to the flow rate of the fluid flow and fluid parameters.

Although FIG. 6 depicts flow sensor 10 as including temperature sensor 58, static pressure sensor 59, and processing electronics 50, the above-described embodiments of flow sensor 10 could include some, none, or all of these components.

FIG. 9 shows an example of how flow sensor 10 can be installed in pipe 12. Pipe 12 is configured to include first and second flange portions 60, 62. Flow sensor 10 is sandwiched between first and second flange portion 60, 62 at peripheral edge portion 64 of flow sensor 10. O-rings 66 are compressed between peripheral edge

-16-

portion 64 and first and second flange portion 60, 62 to provide leakage protection. Alternatively, O-rings 66 could be replaced with fiber gaskets, metal gaskets, or other suitable sealers. Bolts 68 secure the insulation of flow sensor 10. Signals produced by flow sensor 10, including a flow rate signal, a differential pressure signal, and signals relating to flow parameters such as temperature and line pressure, can be accessed at terminals 70 which electronically communicate with flow sensor 10 over wires 72.

FIG. 10 illustrates another aspect of the invention. In FIG. 10, a differential pressure sensor 100 comprises two absolute or gauge pressure sensors 102A and 102B. The differential pressure is a function of a difference between the outputs from sensors 102A and 102B. Sensors 102A and 102B couple to process fluid through opening 104A and 104B across diaphragms or coatings 106A and 106B, respectively. The difference can be determined using analog circuitry or microprocessor 54.

Another aspect of the invention is illustrated in FIGS. 11 and 12. Here, flow restriction member 20 includes a plate 110 that does not have an orifice, but is configured to operate in bi-directional fluid flows. Differential pressure sensor 22 and the other components of flow sensor 10 discussed above are not shown to simplify the illustrations. Here plate 110 attaches to pipe 12

-17-

and can extend either partially into (FIG. 11) or across (FIG. 12) fluid flow passageway 28 to produce the discontinuity in the fluid flow. The resulting pressure drop across first and second sides 24, 26 of plate 110 can be measured by differential pressure sensor 22 (not shown) which preferably embedded to plate 110, as discussed above. Additionally, these embodiments of flow sensor 10 can also include processing electronics 50, temperature sensor 58, and static pressure sensor 59, as in the previous embodiments of flow sensor 10. Although first and second sides 24, 26 are depicted as being parallel to each other, they can be non-parallel to each other as well to form wedge elements. FIGS. 13a-f show examples of plate 110 as seen by the fluid flow. Plate 110 can be shaped in many different ways to form the desired discontinuity in the fluid flow. These shapes include, for example, rhomboidal (FIG. 13 b), rectangular (FIGS. 13 c and f), triangular (FIG. 13 d), semicircular (FIG. 13 e), and other shapes.

Yet another aspect of the invention is illustrated in FIG. 14. In this embodiment, flow restriction member 20 includes first and second ports 112A and 112B corresponding to first and second sides 24, 26. First and second ports 112A, 112B couple the pressure at first and second sides 24, 26, respectively, to differential pressure sensor 22. Differential pressure sensor 22 is preferably a

-18-

piezoresistive pressure sensor. This embodiment allows differential pressure sensor 22 to be located proximate the exterior of flow sensor 10, thereby providing easy access to differential pressure sensor 22. Flow restriction member 20 is depicted in FIG. 14 as being formed of first and second portions 114A and 114B with varying flow areas which constrict the fluid flow and form the desired discontinuity. However, the embodiments of flow restriction member 20 discussed above can also incorporate first and second pressure ports 112A and 112B to allow differential pressure sensor 22 to be positioned proximate the exterior surface of flow sensor 10. Bleed screws or Drain/vent valves (not shown) can be fluidically coupled to first and second ports 112A and 112B to release unwanted gas and fluid contained in first and second ports 112A and 112B. Seals 116 provide leakage protection and retain the static pressure in pipe 12.

In addition to being useful in the process control industry (FIG. 1), other applications can make use of the bi-directional flow rate measuring/monitoring capability of flow sensor 10. For example, flow sensor 10 could be used in hydraulic systems to determine the position of a piston contained within a hydraulic cylinder of a hydraulic actuator. Here the position of the piston within the hydraulic actuator is a function of the volume of hydraulic fluid contained within the

-19-

hydraulic cylinder. The position of the piston is thus controlled by a hydraulic fluid flow that feeds hydraulic fluid into and out of the hydraulic cylinder. By connecting flow sensor 10 to the
5 hydraulic fluid flow, the volume of hydraulic fluid in the hydraulic cylinder can be calculated. As a result, the position of the piston within the hydraulic cylinder can be determined as a function of the volume of the hydraulic fluid in the hydraulic
10 cylinder.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without
15 departing from the spirit and scope of the invention. For example, any type of pressure sensor, configuration of electronics or configuration of orifice plate can be used.

-20-

WHAT IS CLAIMED IS:

1. A bi-directional differential pressure flow sensor, comprising:
 - 5 a bi-directional flow restriction member adapted to produce a pressure drop when placed inline with a fluid flow;
 - a differential pressure sensor embedded in the bi-directional flow restriction member and adapted to produce a differential pressure signal that is indicative of the pressure drop; and
 - 10 processing electronics adapted to produce a flow rate signal that is indicative of a direction and a flow rate of the fluid flow as a function of the differential pressure signal.
2. The flow sensor of claim 1, wherein the bi-
20 directional flow restriction member is an orifice plate having a fluid flow passageway extending between symmetric first and second throat portions.
3. The flow sensor of claim 1, including a
25 temperature sensor embedded in the bi-directional flow restriction member and adapted to sense at least one of a temperature of the fluid flow and an operating temperature of the differential pressure

-21-

sensor and to produce a temperature signal that is indicative of the sensed temperature.

4. The flow sensor of claim 3, wherein the
5 flow rate signal is further a function of the temperature signal.

5. The flow sensor of claim 1, including a
static pressure sensor embedded in the bi-directional
10 flow restriction member and adapted to sense a line pressure of the fluid flow and produce a line pressure signal that is indicative of the sensed line pressure.

15 6. The flow sensor of claim 5, wherein the flow rate signal is further a function of the line pressure signal.

7. The flow sensor of claim 1, including:
20 a temperature sensor embedded in the bi-directional flow restriction member and adapted to sense at least one of a temperature of the fluid flow and an operating temperature of the
25 differential pressure sensor and to produce a temperature signal that is indicative of the sensed temperature; and

-22-

5 a static pressure sensor embedded in the
bi-directional flow restriction member
and adapted to sense a line pressure
of the fluid flow and produce a line
pressure signal that is indicative of
the sensed line pressure.

8. The flow sensor of claim 7, wherein the
flow rate signal is further a function of the
10 temperature signal and the line pressure signal.

9. The flow sensor of claim 1, wherein the
processing electronics embedded in the flow
restriction member.

15 10. The flow sensor of claim 1, wherein the
differential pressure sensor is a piezoresistive
differential pressure sensor.

20 11. The flow sensor of claim 1, wherein the
differential pressure sensor is a capacitance-based
pressure sensor.

25 12. The flow sensor of claim 1, wherein:
the bi-directional flow restriction member
includes symmetric first and second
sides having corresponding first and
second openings; and

-23-

the differential pressure sensor is exposed
to the fluid flow at the first and
second sides of the bi-directional
flow restriction member through the
5 first and second openings.

13. The flow sensor of claim 12, wherein the
differential pressure sensor is isolated from the
fluid flow by a coating.
10

14. The flow sensor of claim 13, wherein the
coating is grease.

15. The flow sensor of claim 13, wherein the
15 coating is a potting material.

16. The flow sensor of claim 1, wherein:
the bi-directional flow restriction member
includes symmetric first and second
20 sides having corresponding first and
second openings filled with a fill
fluid and sealed with first and second
flexible diaphragms, respectively; and
the differential pressure sensor is exposed
25 to the fill fluid in the first and
second cavities; whereby the
differential pressure sensor is
isolated from the fluid flow and

-24-

coupled to the pressure drop through the fill fluid.

17. The flow sensor of claim 1, wherein the
5 flow rate signal is in accordance with one of an analog communication protocol and a digital communication protocol.

18. The flow sensor of claim 17, wherein the
10 flow rate signal is in accordance with a digital communication protocol selected from the group consisting of Highway Addressable Remote Transducer (HART®), FOUNDATION™ Fieldbus, Profibus PA, Profibus DP, Device Net, Controller Area Network (CAN), and
15 Asi communication protocols.

19. The flow sensor of claim 17, wherein the flow rate signal is a 4-20 mA analog signal.

20 20. The flow sensor of claim 1, wherein:
the bi-directional flow restriction member includes symmetric first and second sides; and
the differential pressure sensor includes
25 first and second pressure sensors adapted to produce first and second pressure signals indicative of first and second pressures corresponding to

-25-

the first and second sides,
respectively;

the differential pressure signal is a
function of a difference between the
first and second pressure signals.

5

21. The flow sensor of claim 1, further
including an output related to a process variable.

10 22. The flow sensor of claim 21, wherein the
process variable is selected from the group of
process variables consisting of temperature, static
pressure and differential pressure.

15 23. The flow sensor of claim 1, wherein the bi-
directional flow restriction member includes a plate
that extends into the fluid flow.

24. The flow sensor of claim 1, wherein the bi-
20 directional flow restriction member includes a plate
that extends across the fluid flow.

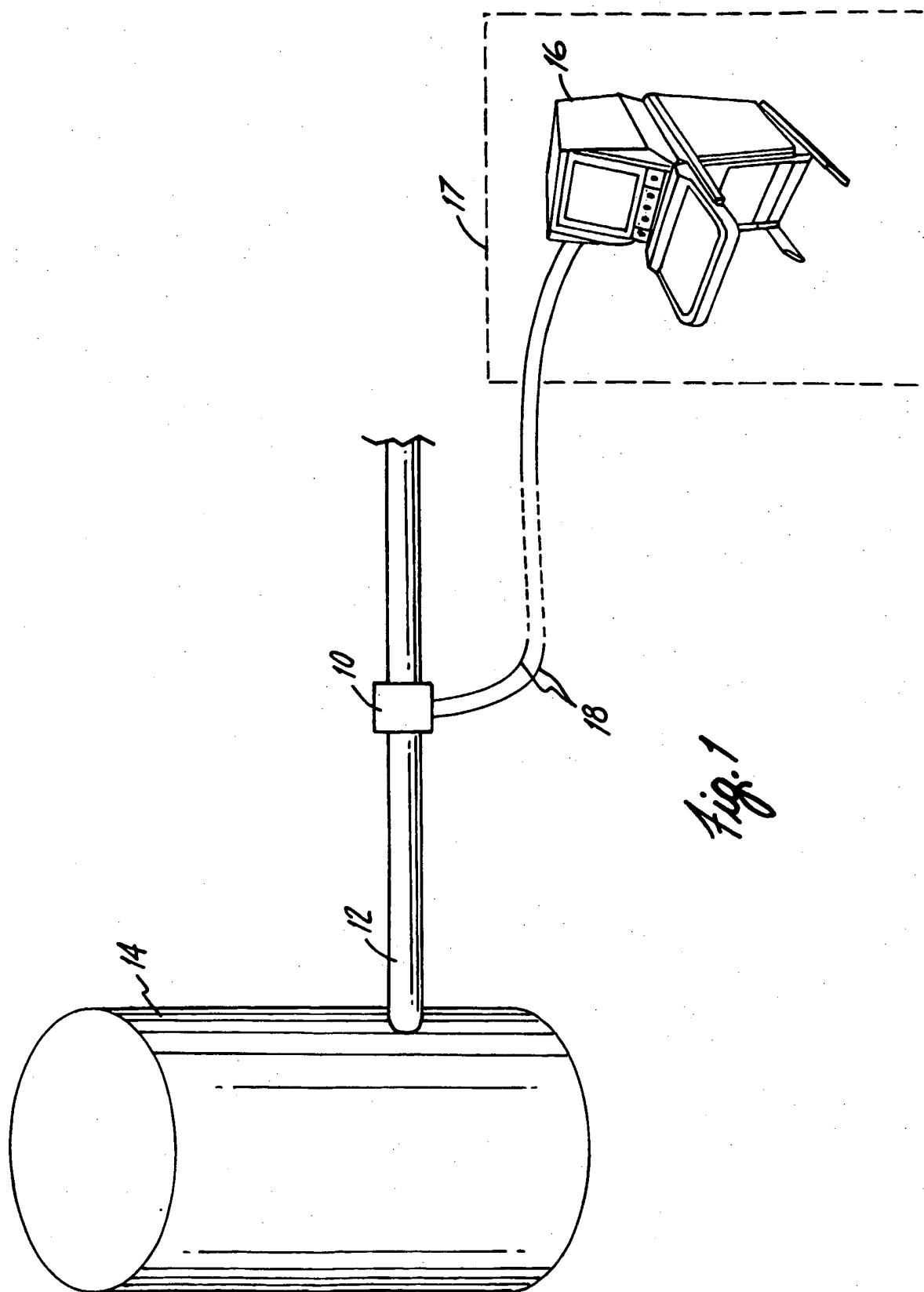
25. The flow sensor of claim 24, wherein the
plate has a shape, as viewed by the fluid flow, that
25 is selected from the group consisting of rhomboidal,
rectangular, triangular, and semicircular.

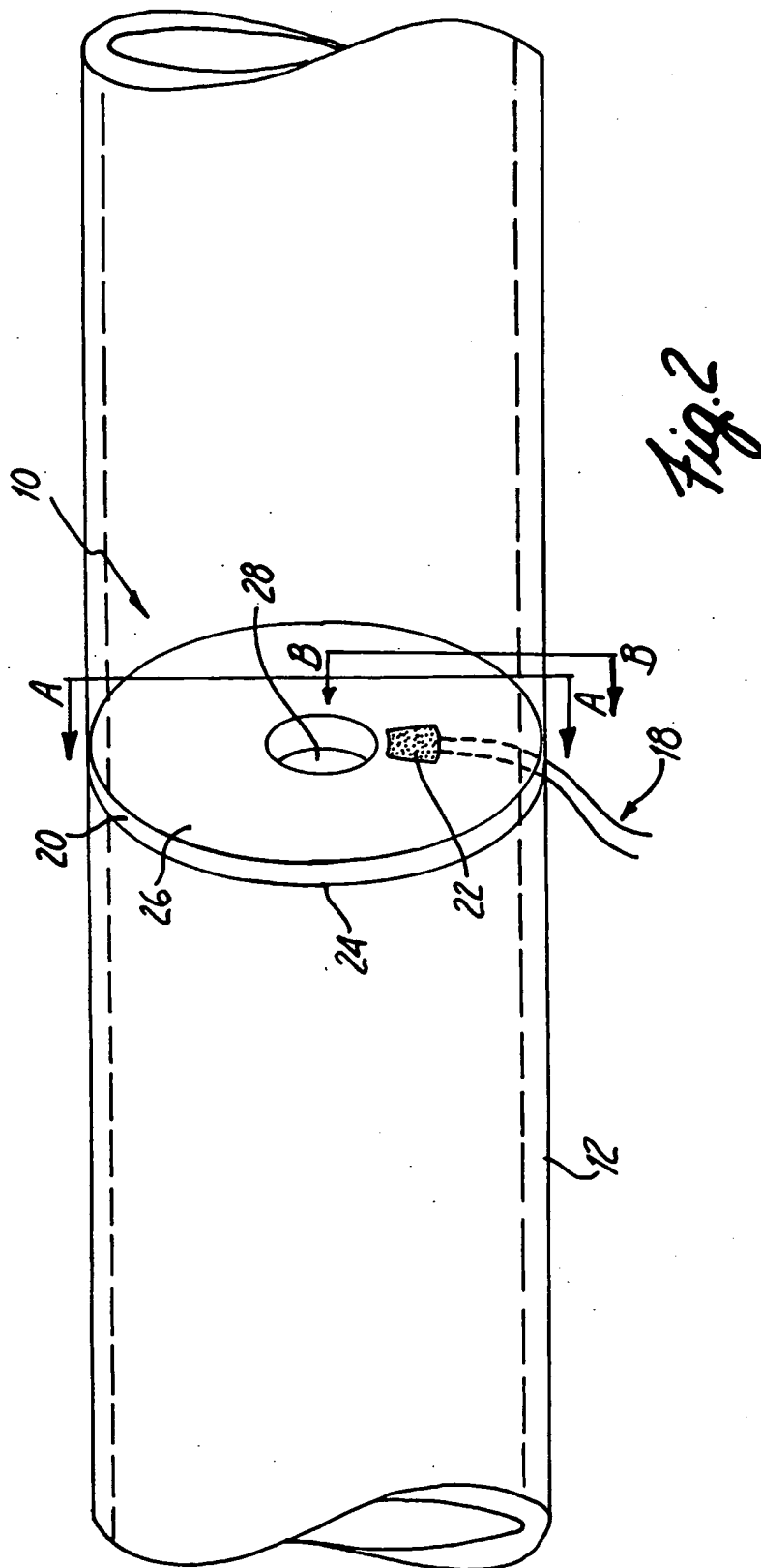
26. The flow sensor of claim 1, wherein the bi-
directional flow restriction member includes first

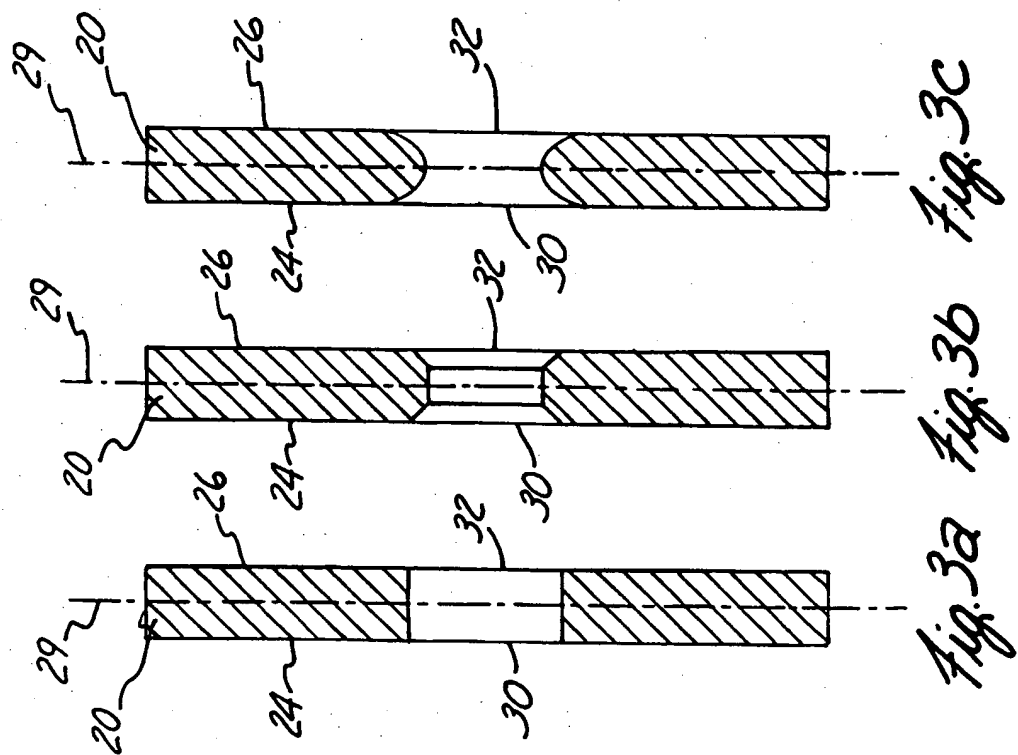
-26-

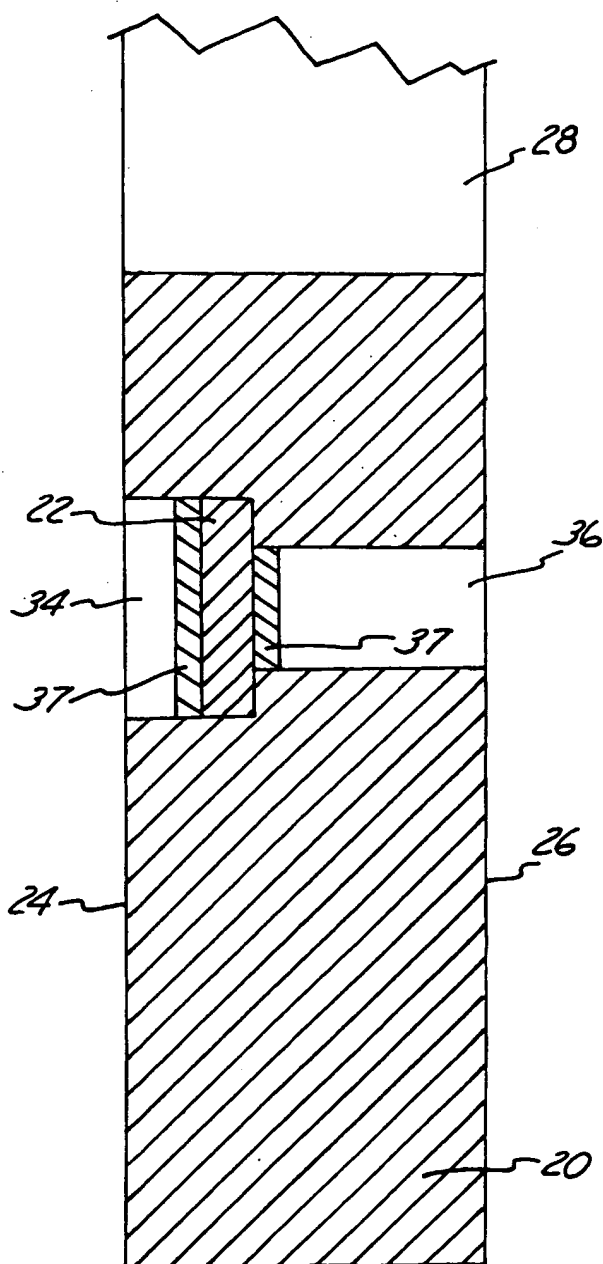
and second pressure ports, the first and second pressure ports couple the pressure drop to the differential pressure sensor, whereby the differential pressure sensor can sense the pressure drop.

27. The differential pressure flow sensor of claim 9, wherein the flow rate signal is further a function of at least one of temperature and line pressure.







*Fig. 4*

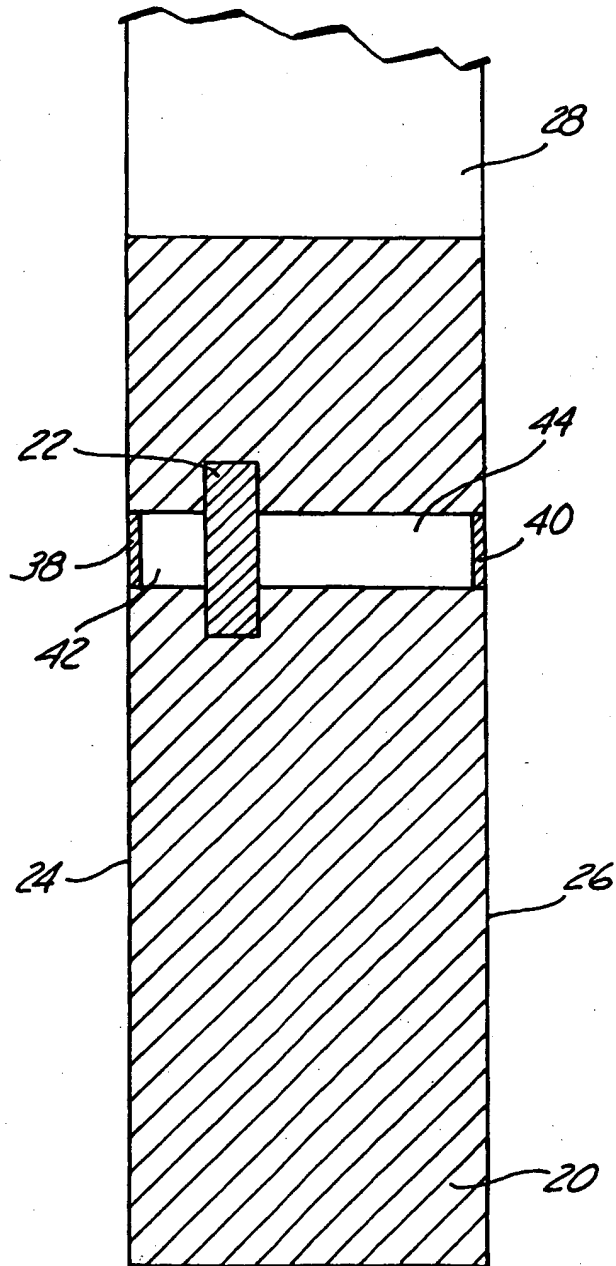


Fig. 5

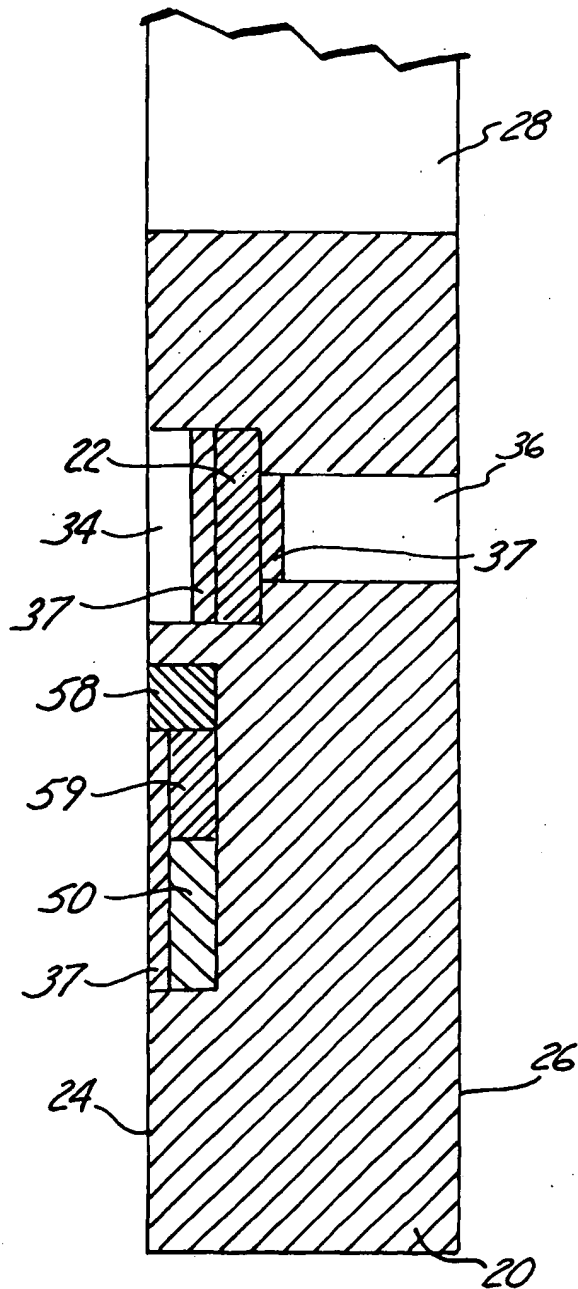
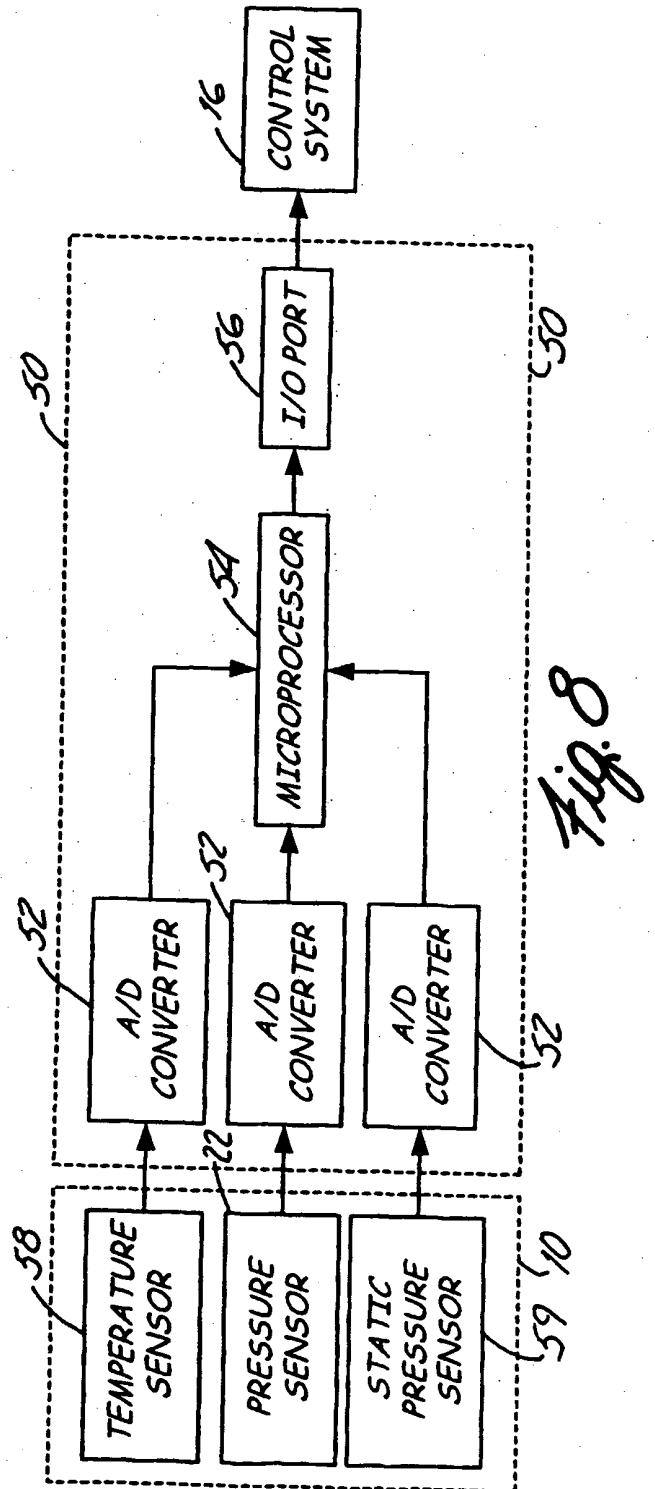
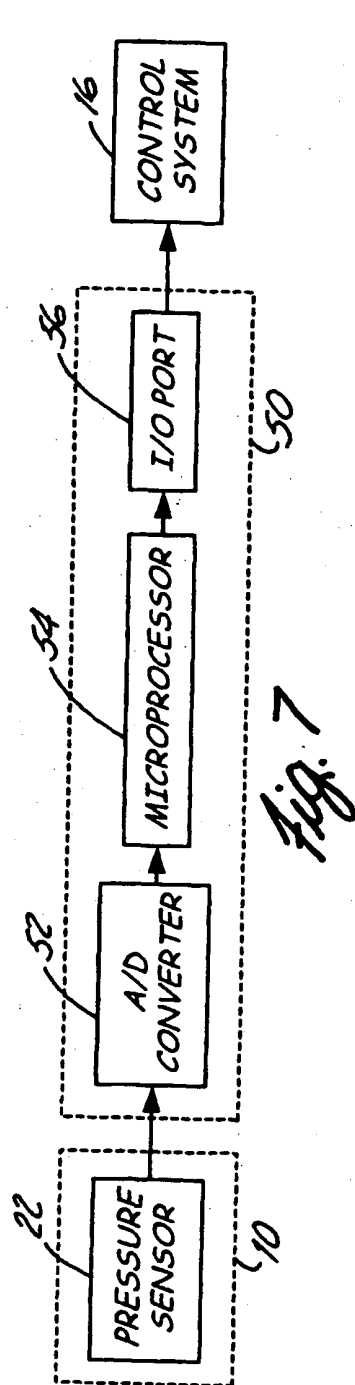
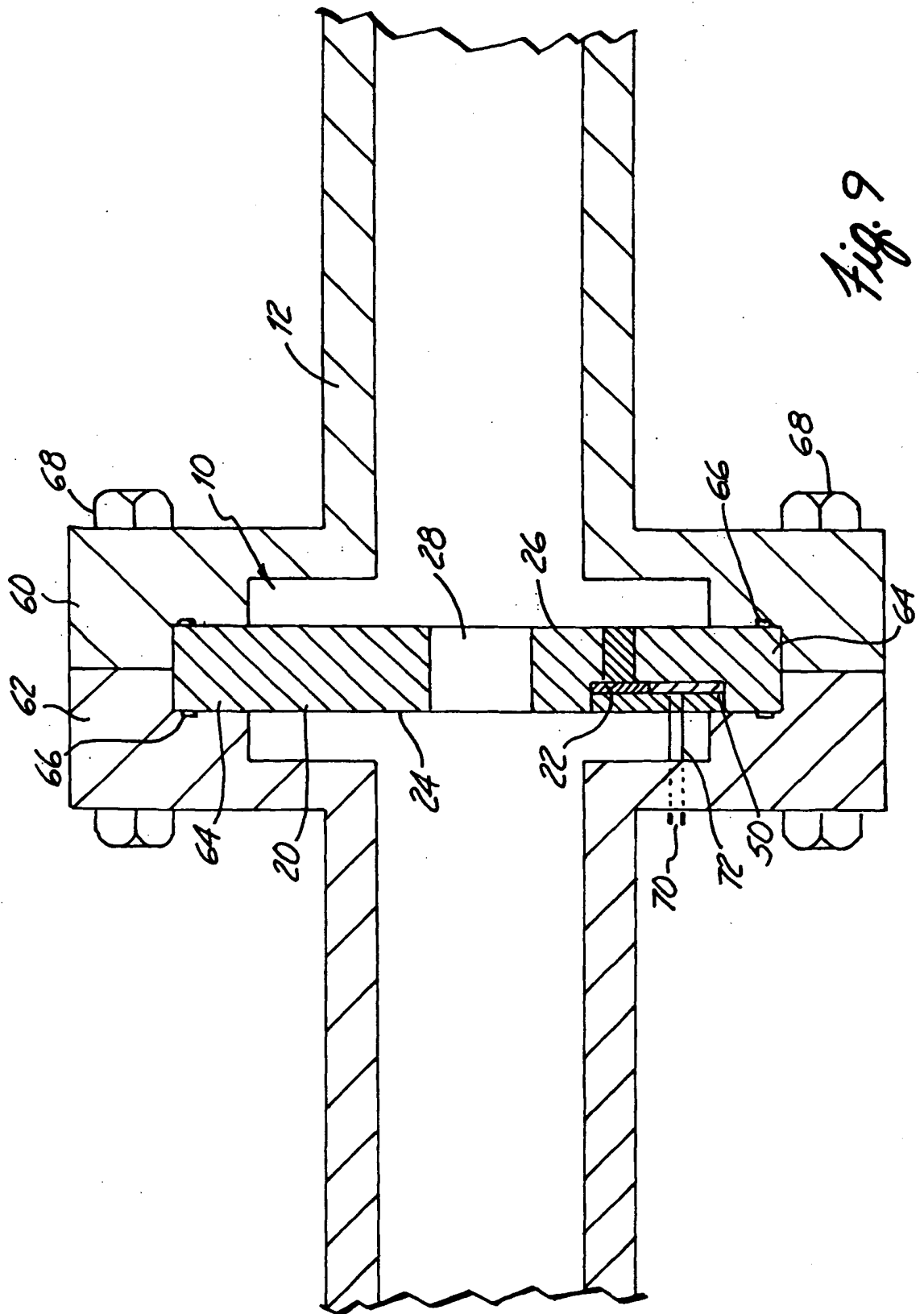


Fig. 6





SUBSTITUTE SHEET (RULE 26)

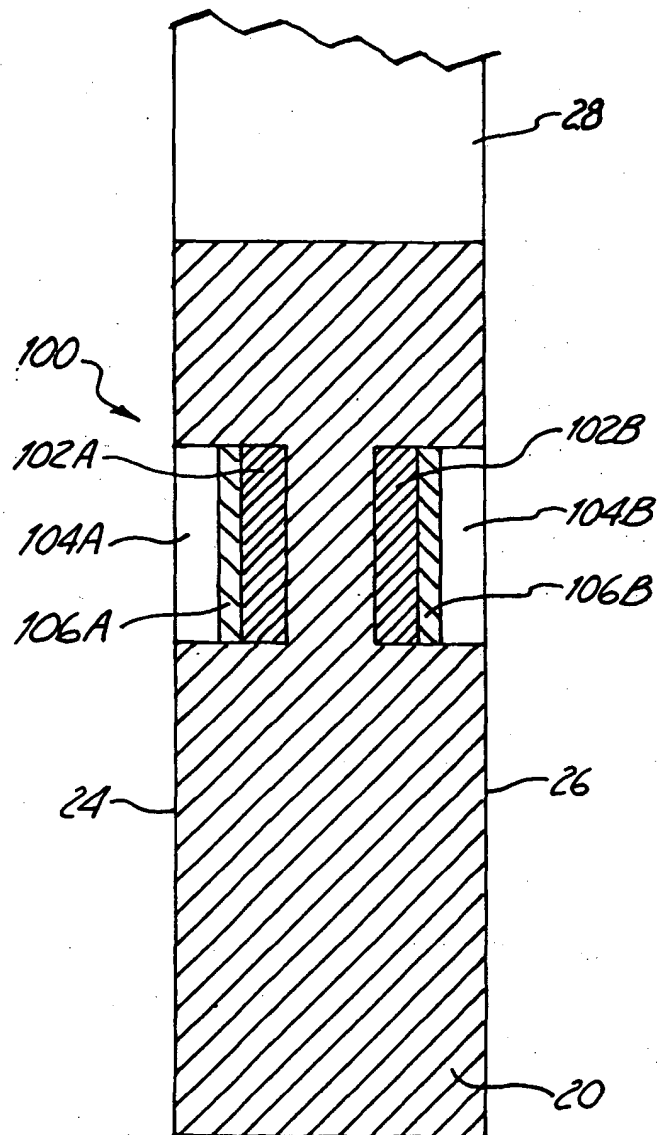


Fig. 10

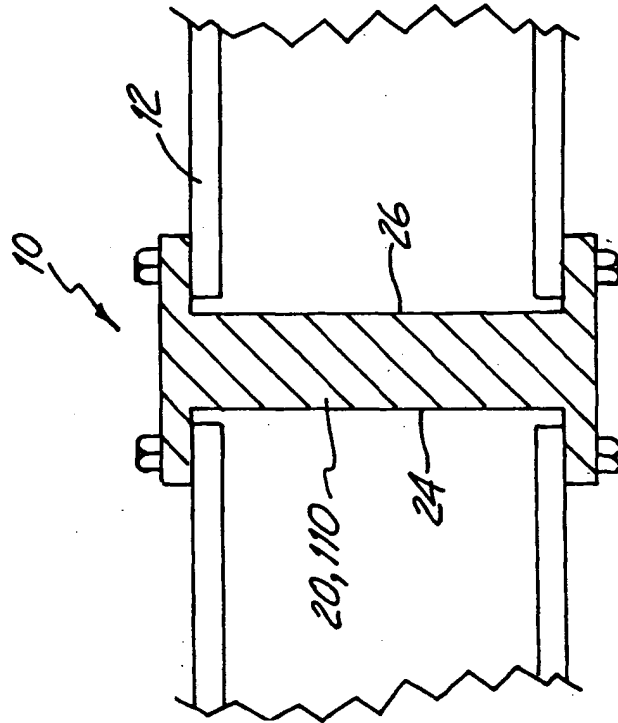


Fig. 12

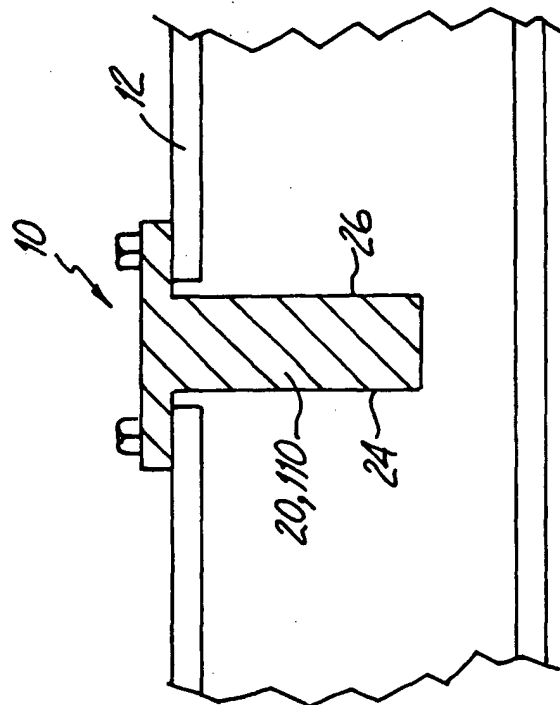


Fig. 11

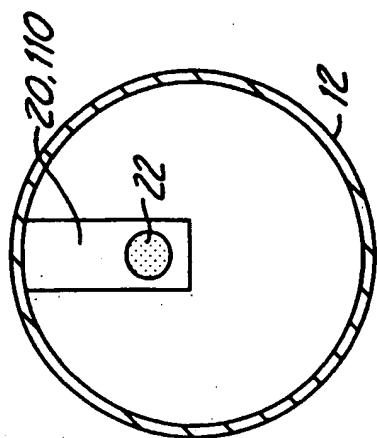


Fig. 13c

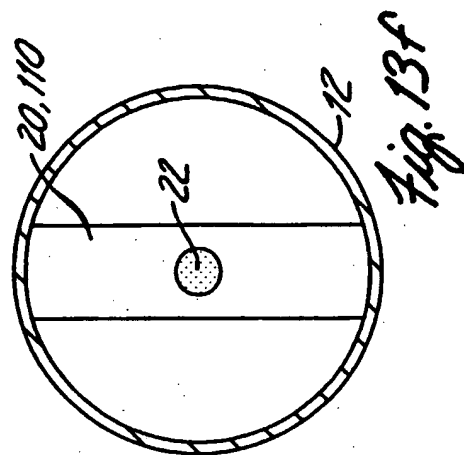


Fig. 13f

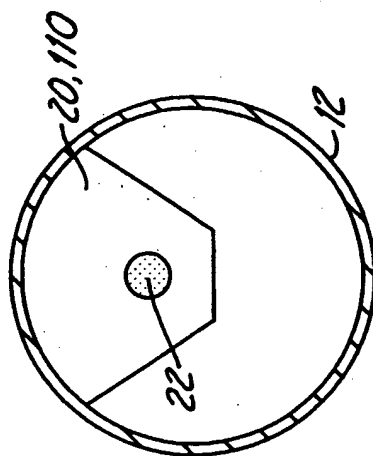


Fig. 13b

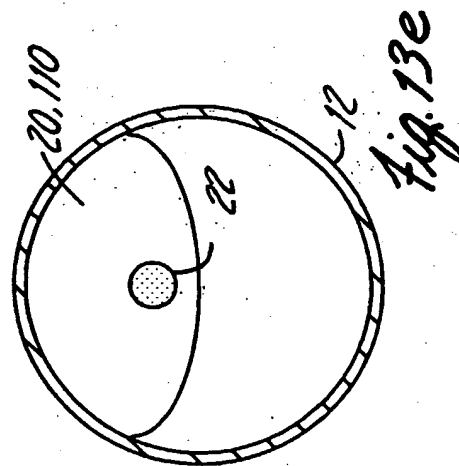


Fig. 13e

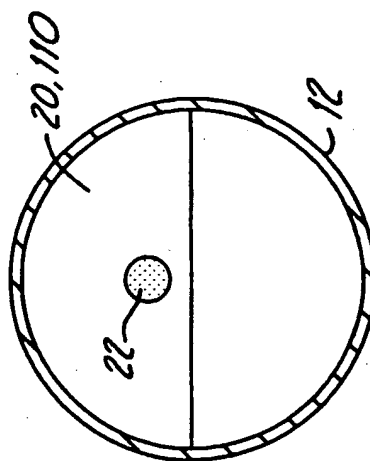


Fig. 13a

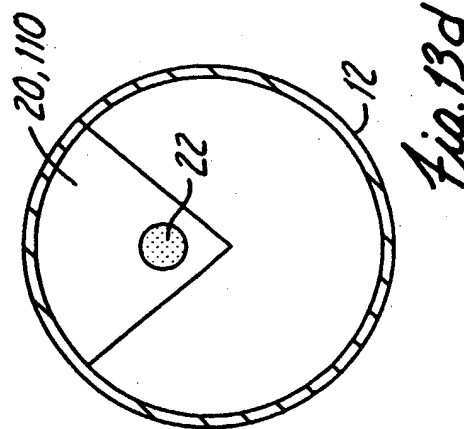


Fig. 13d

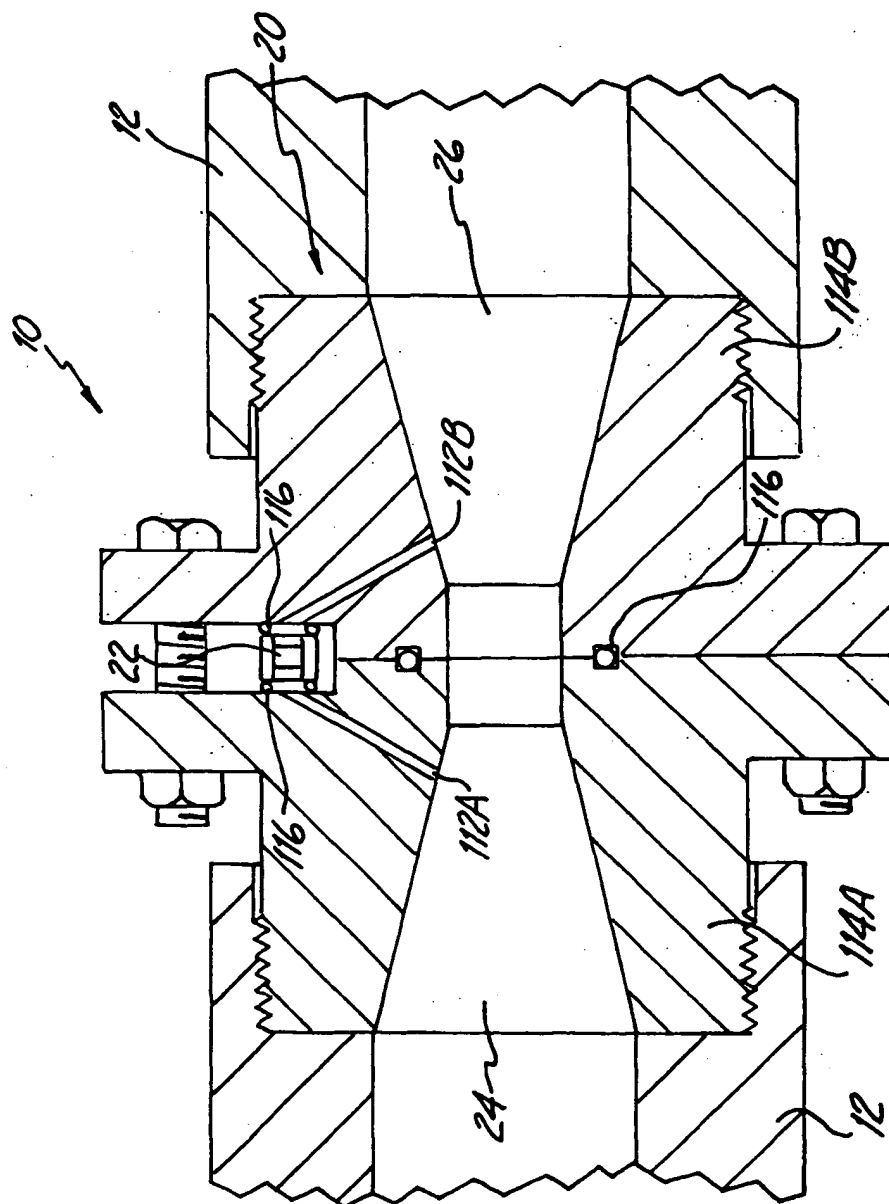


Fig. 14

This Page Blank (uspto)

(19) World Intellectual Property Organization
International Bureau



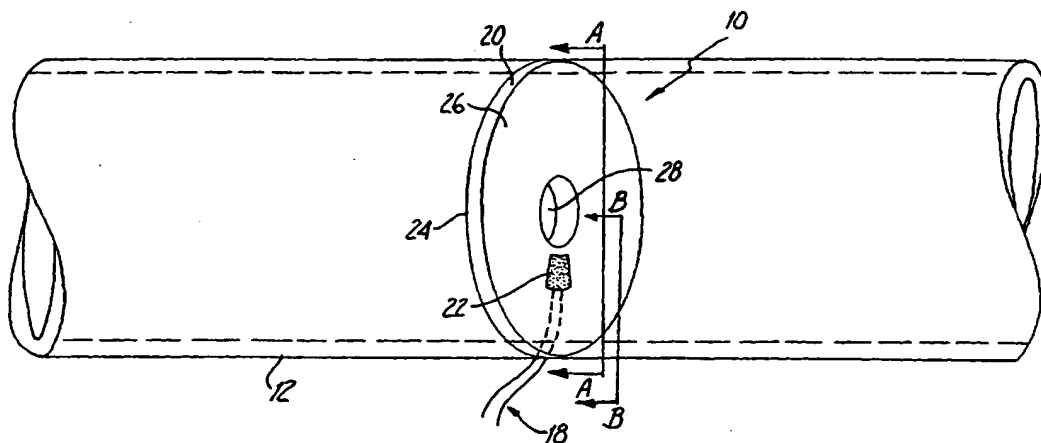
(43) International Publication Date
13 September 2001 (13.09.2001)

PCT

(10) International Publication Number
WO 01/66955 A3

- (51) International Patent Classification⁷: F15B 15/28. G01F 1/00
- (21) International Application Number: PCT/US01/05639
- (22) International Filing Date: 22 February 2001 (22.02.2001)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
09/521,537 8 March 2000 (08.03.2000) US
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW). Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM). European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR). OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
- (71) Applicant: ROSEMOUNT INC. [US/US]; 12001 Technology Drive, Eden Prairie, MN 55344 (US).
- Published:
— with international search report
- (72) Inventors: WIKLUND, David, E.: 17918 South Shore Lane West, Eden Prairie, MN 55346 (US). KROUTH, Terrence, F.: 8722 Stanley Trail, Eden Prairie, MN 55347 (US). BRODEN, David, A.: 3045 166th Lane N.W., Andover, MN 55301 (US). SCHUMACHER, Mark, S.: 322 East Minnehaha Parkway, Minneapolis, MN 55419 (US).
- (88) Date of publication of the international search report:
7 February 2002
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
- (74) Agents: KAUL, Brian, D. et al.: Westman, Champlin & Kelly, P.A., International Centre, Suite 1600, 900 Second Avenue South, Minneapolis, MN 55402-3319 (US).

(54) Title: BI-DIRECTIONAL DIFFERENTIAL PRESSURE FLOW SENSOR



(57) Abstract: Disclosed is a bi-directional differential pressure flow sensor (10) that is configured to establish a direction and flow rate of a fluid flow. The flow sensor (10) includes a flow restriction member (20), a differential pressure sensor (22), and processing electronics (50). The flow restriction member (20) is configured to produce a pressure drop when placed inline with the fluid flow. The differential pressure sensor (22) is embedded or integral with the flow restriction member and produces a differential pressure signal that is indicative of the pressure drop. The processing electronics (50) produces a flow rate signal that is indicative of the direction and flow rate of the fluid flow as a function of the differential pressure signal.

WO 01/66955 A3

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 01/05639

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F15B15/28 G01F1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01F F15B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|---|----------------------------------|
| X | US 5 576 498 A (SHAMBAYATI) 19 November 1996 (1996-11-19) column 5, line 12 - line 19 column 5, line 28 - line 37 column 6, line 1 - line 6 figures 9,10,13,14 | 1,3-8, 10-12, 16-26 |
| X | US 4 304 136 A (MCCABE) 8 December 1981 (1981-12-08) column 6, line 1 - line 43; figure 8 -/-- | 1,3,4, 10, 17-19, 23,26 |



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

* Special categories of cited documents:

A document defining the general state of the art which is not considered to be of particular relevance

E earlier document but published on or after the international filing date

L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

O document referring to an oral disclosure, use, exhibition or other means

P document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

Z document member of the same patent family

Date of the actual completion of the international search

4 October 2001

Date of mailing of the international search report

12/10/2001

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

SLEIGHTHOLME, G

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 01/05639

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|--|-----------------------|
| A | NISHIMOTO T ET AL: "BURIED PIEZORESISTIVE SENSORS BY MEANS OF MEV ION IMPLANTATION" SENSORS AND ACTUATORS A, ELSEVIER SEQUOIA S.A., LAUSANNE, CH, vol. A43, no. 1/3, 1 May 1994 (1994-05-01), pages 249-253, XP000454119 ISSN: 0924-4247 page 251; figure 7A --- | 9,10,24, 25 |
| A | EP 0 309 643 A (LANDIS & GYR) 5 April 1989 (1989-04-05) column 1, line 48 -column 2, line 2; figure 1 --- | 1 |
| A | PATENT ABSTRACTS OF JAPAN vol. 013, no. 511 (P-961), 16 November 1989 (1989-11-16) & JP 01 207634 A (YOKOGAWA ELECTRIC CORP), 21 August 1989 (1989-08-21) abstract --- | 1 |
| A | GB 2 259 147 A (PREMIERFORCE) 3 March 1993 (1993-03-03) abstract; figure 3 --- | 11 |
| A | GB 2 155 635 A (BESTOBELL) 25 September 1985 (1985-09-25) abstract; figure 3B --- | 15 |
| A | GB 1 080 852 A (GEN ELECTRIC) 23 August 1967 (1967-08-23) claim 1; figure --- | 16 |
| A | PATENT ABSTRACTS OF JAPAN vol. 012, no. 295 (P-743), 11 August 1988 (1988-08-11) & JP 63 070121 A (TOKYO KEISO KK), 30 March 1988 (1988-03-30) abstract --- | 24,25 |
| A | EP 0 331 772 A (PPG HELIGE) 13 September 1989 (1989-09-13) --- | |
| A | WO 96 24028 A (BOUCHER) 8 August 1996 (1996-08-08) --- | |
| A | FR 2 485 724 A (COMMISSARIAT ENERGIE ATOMIQUE) 31 December 1981 (1981-12-31) ----- | |

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 01/05639

| Patent document cited in search report | | Publication date | Patent family member(s) | Publication date |
|---|---|---------------------|----------------------------|---------------------|
| US 5576498 | A | 19-11-1996 | US 5763791 A | 09-06-1998 |
| US 4304136 | A | 08-12-1981 | CA 1139590 A1 | 18-01-1983 |
| | | | DE 3102035 A1 | 10-12-1981 |
| | | | FR 2475217 A1 | 07-08-1981 |
| | | | GB 2068560 A ,B | 12-08-1981 |
| | | | IT 1167821 B | 20-05-1987 |
| | | | US 4315436 A | 16-02-1982 |
| EP 0309643 | A | 05-04-1989 | EP 0309643 A1 | 05-04-1989 |
| JP 01207634 | A | 21-08-1989 | NONE | |
| GB 2259147 | A | 03-03-1993 | GB 2259157 A | 03-03-1993 |
| GB 2155635 | A | 25-09-1985 | NONE | |
| GB 1080852 | A | 23-08-1967 | US 3342072 A | 19-09-1967 |
| | | | DE 1573534 A1 | 17-12-1970 |
| JP 63070121 | A | 30-03-1988 | JP 1864123 C | 08-08-1994 |
| | | | JP 5069368 B | 30-09-1993 |
| EP 0331772 | A | 13-09-1989 | EP 0331772 A1 | 13-09-1989 |
| | | | JP 1311229 A | 15-12-1989 |
| WO 9624028 | A | 08-08-1996 | US 5641915 A | 24-06-1997 |
| | | | AU 711838 B2 | 21-10-1999 |
| | | | AU 5021396 A | 21-08-1996 |
| | | | BR 9605299 A | 16-09-1997 |
| | | | CA 2187029 A1 | 08-08-1996 |
| | | | EP 0754293 A1 | 22-01-1997 |
| | | | NO 964171 A | 03-12-1996 |
| | | | NZ 303801 A | 28-07-1998 |
| | | | PL 316637 A1 | 03-02-1997 |
| | | | WO 9624028 A1 | 08-08-1996 |
| | | | US 5717146 A | 10-02-1998 |
| | | | US 5905208 A | 18-05-1999 |
| | | | US 5834659 A | 10-11-1998 |
| | | | US 5827977 A | 27-10-1998 |
| | | | US 5886267 A | 23-03-1999 |
| FR 2485724 | A | 31-12-1981 | FR 2485724 A1 | 31-12-1981 |